DS-VBF: Dual Sink Vector-Based Routing Protocol for Underwater Wireless Sensor Network

Maryam Pouryazdanpanah K.*, Mohammadfazel Anjomshoa*, Ahmad Salehi S.‡, Amir Afroozeh§, Marjan Moshfegh G.*
*Faculty of Computing, Universiti Teknologi Malaysia (UTM), Skudai, 81300 Johor , Malaysia
e-mail: {pkmaryam2, amohammadfazel2, mgmarjan2}@live.utm.my
‡Faculty of Engineering and Science, Queensland University of Technology (QUT), Brisbane QLD 4000, Australia
e-mail: a.salehishahraki@qut.edu.au
§Department of Computer and Networks, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
e-mail: amira@stud.ntnu.no

***Abstract*—Underwater wireless sensor networks (UWSNs) have become the seat of researchers' attention recently due to their proficiency to explore underwater areas and design different applications for marine discovery and oceanic surveillance. One of the main objectives of each deployed underwater network is discovering the optimized path over sensor nodes to transmit the monitored data to onshore station. The process of transmitting data consumes energy of each node, while energy is limited in UWSNs. So energy efficiency is a challenge in underwater wireless sensor network. Dual sinks vector based forwarding (DS-VBF) takes both residual energy and location information into consideration as priority factors to discover an optimized routing path to save energy in underwater networks. The modified routing protocol employs dual sinks on the water surface which improves network lifetime. According to deployment of dual sinks, packet delivery ratio and the average end to end delay are enhanced. Based on our simulation results in comparison with VBF, average end to end delay reduced more than 80%, remaining energy increased 10%, and the increment of packet reception ratio was about 70%.**

Keywords*—Underwater Wireless Sensor Networks(UWSN); Routing Protocol; Wireless Sensor Networks(WSN); Location-Based Routing; Energy Efficiency; Multiple Sink Architecture

I. INTRODUCTION

As a the vital role of the ocean in the humanity's life, it is obvious that every change in the Earth's water will affect on human life so more effort should be done to explore these areas [1]. Underwater wireless sensor networks (UWSNs) were introduced to enable many discovering applications for example: pollution and environmental monitoring, climate recording, oceanographic data collection, offshore exploration, disaster prevention, tactical surveillance, seismic monitoring [2], [3]. Underwater wireless sensor networks consist of sensor nodes and vehicles which are designed to perform collaborative tasks to support different applications over a specified geographical area [4]. Underwater sensors nodes and vehicles must be able to manage their operation by exchanging configuration, location, and updated information of nodes movement and to transfer sensed data to onshore stations over a wireless connection [5].

The main objective of this paper is proposing an algorithm to address energy efficiency in the underwater wireless sensor networks. Several routing protocols have been introduced for underwater sensor networks in recent years that assumed all nodes are static which is impossible based on water flow. The contributions of this research work are to increase the packet delivery ratio and also lifetime of network by applying multi-sink architecture. In our architecture it is assumed that all nodes are dynamic and know about the positions of all the other nodes and themselves (geographical routing protocol). Furthermore, residual energy of each sensor node is taken into consideration to provide a balanced energy consumption in the entire network.

The rest of this paper is structured as follows. Section (II) describes the related works of this study. Section (III) provides an overview on VBF concept. Section (IV) shows the proposed routing protocol and research methodology. Section (V) presents the final results and explains the simulation output graphs and discusses over the results and lastly section (VI) illustrates the conclusion of this study.

II. RELATED WORKS

Vector based forwarding(VBF) [6] is one of the primary routing protocols which was proposed for mobile UWSNs. It is a geographic routing approach that assumes every sensor node is aware of its own location and each data packet contains the location information of the source, target, forwarder nodes and also a range field which is used for node mobility notion. In data forwarding process limited number of nodes are participated and the state information is not needed for nodes.

VBF is too sensitive to routing pipe. In order to solve this problem a new routing protocol named Hop-by-Hop Vector-Based Forwarding [7] was presented. The basic concept of routing vector in HH-VBF is homogeneous to VBF however it forms the routing pipe in a hop-by-hop fashion from each intermediate forwarding node to the sink. Because of no usage of a unique virtual forwarding pipe each node transmits packet in accordance with its own location. By applying this method, even in sparse networks, HH-VBF can detect a forwarding path as long as there is an available node in the forwarding path. Since each node forms a new routing pipe, this mechanism is not too sensitive to a predefined virtual routing pipe radius. Therefore, the packet delivery ratio enhances significantly. In this algorithm the end to end delay and consuming energy are high because each node overhears the duplicated data and waits for some time to select the best node to forward the data packet.

Afterwards Vector-Based Void Avoidance (VBVA) [8] was proposed based on vector based protocol to address the void problem for routing in mobile underwater wireless sensor networks. In VBVA whenever a routing void happens in network, it applies two methods; vector shift and back pressure otherwise it acts same as VBF. Although the aforementioned protocols are designed to provide a powerful and scalable network but end to end delay is almost high. Vector based forwarding protocol(N-VBF) [9] presented a low delay routing protocol to sate demanding for reducing the delay in underwater networks. This protocol brings forth a novel mechanism for node selection and forwarding procedure, that is a vector based algorithm. Despite considering end to end delay in N-VBF protocol, all nodes consume extra energy to save data in their memory so this method is not energy efficient too.

As energy efficiency is an important issue in the underwater wireless sensor network. In 2012, VBF team proposed an energy efficient protocol to increase the network lifetime of VBF protocol. This method [10] considers both position information and energy status to select a node as a forwarder. Life extended vector based routing protocol (LE-VBF) redefines how desirableness factor is calculated by considering energy information same as position information. every data packet contains both average energy and position information. Although LE-VBF is energy efficient and scalable according to adjusting network to the required size, but the average end to end delay is large as they employ just one sink at the water surface.

ES-VBF [11] considered both position and energy residual energy information to calculate desirableness factor. In energy saving vector based routing protocol(ES- VBF) if the remaining energy of the nodes is more than 60% of initial energy, desirableness factor is calculated like VBF protocol but if residual energy is less than 60%, residual energy is taking into consideration to calculate a new desirableness factor. So nodes with higher residual energy, have smaller desirableness factor, higher priority of forwarding packets and shorter waiting time between neighbouring nodes. By implementing this algorithm, they increase the residue energy, reduce the value of mean square error and prolong the life time of the network without worsening the packet reception ratio (PRR) apparently.

Localization is an essential information for location-based routing protocol hence the location information of all nodes is required in this kind of protocols. Depth based routing [12] presents a novel idea to address the localization problem in UWSN. Depth information is enough to route a path through sensor nodes in this study. Each sensor anchored to the bottom of the ocean bed and a depth sensor is inside the sensor node to acquire depth information. Data packet is forwarded through the nodes that have the lower depth priority to multiple surface sinks. The depth information is carried by data packet and upon receiving a data, each node calculates its depth to forward the data. This routing protocol is not efficient in sparse networks because of employing the greedy method, which decreases packet delivery in sinks. Also in density network deployment, calculating sensor depth one by one is complicated which wastes the residual energy of a node and consequently as the sensor memory is limited it may cause loosing the data packet.

Seah et al. [13] presented a robust routing protocol that handle the whole network perform properly even if a failure happen in one part of the network. According to the methodology, each underwater network consists of clusters of nodes and each cluster has its own aggregation point.

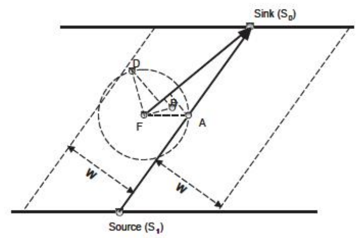

Fig. 1: The forwarding selection in VBF

A multi-sink routing protocol presented by [14] which was designed to achieve high data packet reception in a mesh deployment network. It takes quasi-stationary 2D underwater wireless sensor network architecture into consideration and the coverage area is just shallow water near to the coastal area. They assumed that the deployment architecture is a 2-tiered network topology in which the ordinary sensors act as sensing, computational, and communication device. These sensors located on the lower tier and were configured as a backbone network that require data forwarding from sensor nodes to the onshore station.

III. Overview On VBF

Routing protocols are designed to transmit monitored data from source (sensor node) to the destinations (surface sinks or station) via intermediate nodes [15]. As VBF is a location based routing approach; it represents a trajectory with a routing vector from the source to the sink. As it is clearly obvious in Figure 1 whenever a packet reaches to a node, this node measures its location to the forwarder node by computing the distance between itself and forwarder and the angle of arrival of acoustic signal. All involved nodes compute their positions recursively, to determine if computed distance is less than a pre-controlled distance threshold, it is close enough to the routing vector so it updates packet forwarder position and continues forwarding procedure, otherwise it discards the data packet. It establishes a routing pipe to choose only the located nodes in virtual pipe for forwarding.

Self-Adaptation algorithm in VBF allows every sensor node calculates the congestion in the neighboring area according to position information and modifies its forwarding path consequently. The desirableness factor is defined as:

$$\alpha = \frac{p}{w} + \frac{R - d * \cos\theta}{R} \tag{1}$$

In equation 1 p is the projection of current sensor node into the routing vector, d demonstrates distance between current node and forwarder. θ is the angle between vector from the forwarder to the node and vector between forwarder and destination (sink) node. R is forwarding range and w indicates routing pipe threshold. Based on the concept of desirableness factor, when a node in the routing pipe receives a packet, it holds the packet for a time interval called $T_{adaptation}$ that is calculated as follow:

$$T_{adaptation} = \sqrt{\alpha} * T_{delay} * \frac{R - d * \cos\theta}{V_0} \quad (2)$$

Where T_{delay} is a predefined threshold, V_0 indicates the spreading speed of acoustical signal in the deep water, R represents transmission zone and d is the distance from current node and the forwarder node. During the T_{delay} period if a node gets a duplicated data packets from neighboring nodes, this node will compare its own desirableness with the others and based on the density of receiving packet, it will make decision to transmit the data or discard it.

The performance of VBF evaluates based on three metrics: packet delivery ratio, energy consumption, and end-to-end delay through simulation in NS-2 [16]. Although greedy policies give the advantage of optimized nodes selection to VBF but these policies are not always feasible [17]. Also there are still some constraints in VBF such as:

1) Vector-based routing protocols are very sensitive to routing pipe radius, that reduces VBF efficiency.
2) Some specific nodes on the routing pipe are used to forward data constantly, which can overuse sensors energy so these nodes are suspected to die earlier than the others.
3) All location based routing protocols like VBF are scalable and robust but they are not effective in low end-to-end delay environment.
4) Decreasing reception ratio will occur in the reflection of the large packet reception ratio that causes packet collisions leading to a large number of packets discard.

IV. Proposed Protocol

To solve the energy problem in UWSN, this research puts forward a new multi-sink routing algorithm, called Dual-Sink Vector Based Forwarding protocol (DS-VBF). In terms of energy efficiency, the routing protocol specifies the number of nodes that are participated in data forwarding and the forwarding path in the network. To do this, a small number of nodes that are located in a pipe (determined by the routing vector), are selected by proposed protocol. In order to increase the packet delivery ratio and reduce the average, dual sinks are deployed hence sensed data from a source node can be sent simultaneously over various routing paths to these sinks. In addition, residual energy of eligible node is taken into consideration so both factors of position and energy consumption are equally crucial in forwarder node selection in our protocol. Dual-Sink vector based routing protocol(DS-VBF) consists of these four steps:

1) Choose the closest sink as the final destination
2) The transmitting path is determined by routing vector from the source node to the final destination.
3) After a data packet reached to a node, current node computes its location to the forwarder by calculating the angle of arrival (AOA) of signals and its distance to the forwarder node. By doing this step, each node distinguishes its position.
4) Nodes that are far away from the forwarding vector simply discard the packet, otherwise nodes should consider their residual energy, and node with the most residual energy among the other nodes on forwarding path will put its position in the packet as the forwarder and sends the packet into the others nodes.

A. Dual-Sink Vector Based Protocol (DS-VBF)

In DS-VBF, we employ dual sinks at the water surface in different locations. We assume that these sink nodes equipped with both acoustic and radio transceivers. The acoustic transceivers are capable of communicating with underwater sensors and radio transceivers are used to connect both sinks with each other and to onshore station. As sink nodes are equipped with radio communication, upon receiving the packet to each of the sinks, the forwarding process is done successfully. The sensor nodes are deployed from the top to the bottom of the deployment region at different depths. The sensor nodes reside at the bottom to sense the monitored data and send it to the surface sinks by relaying it through the sensor nodes at different depths. Hence we revise the routing path according to the dual-sink architecture.

In DS-VBF, we add energy information as a vital parameter same as position to desirableness factor. Each data packet carries various information including location of the source node, forwarder node, destination node, and energy but the information about the destination is variable and defines by following method. In our proposed method, target selection is based on the shortest distance from the source node to surface sinks. After selecting the closest sink, each node will put the sink location as the destination information in the data packet. The forwarding path can specify by each node according to its relative current location to closest sink. Each node also makes its own routing virtual pipe which its radius is equal to transmission range. When a node receives a data packet, it will determine its relative position to the forwarder node by measuring its distance to the forwarder and the angle of arrival (AOA) of the signal. If the current node is not close to the routing vector it discards the data packet otherwise sensor node considers its residual energy. If this node is available in routing pipe, when a node receives a packet, it first gets the minimum energy (E_{min}) from the packet which is passed through it then considering its residual energy and finally estimate β as follows:

$$\beta = \frac{E_{current} - E_{min}}{E_{initial}} \quad (3)$$

Where E_{ccurrent} represent remaining energy of current node, E_{min} is the minimum energy that is extracted from data packet. E_{initial} is the initial energy of the node pass through. According to the β, If remaining energy of this node is lower than the minimum energy of all nodes that participate in forwarding, the node keeps the packet for an interval time. Otherwise it continues same forwarding process. We present the concept of energy availability to specify the priority of a node for forwarding data packet over the network. The value of this notion is measured as follow:

$$\alpha^{'} = \alpha + \beta \quad (4)$$

In DS-VBF, based on figure (scenario) if two nodes locate at the same position on the network but one of them save more energy , this node is more prone for choosing as the forwarder. The ratio of α and β is different according to the scene. As we mention in VBF overview α is measured to define the suitability of a node based on equation 1.

Determine this equation for a node like A, where S_1 is the source and S_0 is the sink, for forwarder F, p is the projection of A on the routing vector, d is the distance between node A and node F, and θ is the angle between $\overrightarrow{FS0}$ and $\overrightarrow{FA}$. R is the transmission range and w is the radius of the routing pipe. Waiting time or $T_{\text{addaptation}}$ for each node is calculated as follows:

$$T_{adaption} = \sqrt{\alpha'} * T_{delay} + \frac{R-d}{v_0} \quad (5)$$

Consequently the waiting time is proportional to residual energy too.Therefore node with a large amount of residual energy will forward the data packet, while other nodes with less energy residual have to wait. If during the waiting time, the node receives the same data from other nodes it should calculate the desirableness factor again to decide whether to transmit data or not. Node selection algorithm is designed to increase energy efficiency in forwarding data.

Algorithm 1: Algorithm for node selections and packet forwarding

```
Get data packet information (SP, TP, FR, R, Emin) from
  packet(p) ;
Compute the distance(D) of source node(sender) to each
  sink;
Choose the shortest distance and update the destination
  information(TP) node in packet(p) ;
Compute the distance(d) from candidate node(FR) to
  it's projection on (S0 S1 );
if d< R then
    Consider E_current of candidate node;
    if E_current > E_min then
        Calculate
            β = (E_current − E_min) / E_initial
            α = (R − d * cos θ) / R
            α' = (0.8)α + (0.2)β
        and send the packet and update min energy in
        the packet(p);
    end
    else
        discard the packet(p);
    end
end
```

In Algorithm 1 we describe the algorithm for node selections and packet forwarding in this research study.

V. Performance Evaluation

In this chapter, the network simulator Aqua-sim [18] is utilized to apply dual sink architecture and energy efficiency priority in the underwater wireless network and the results are illustrated to verify the validity of proposed technique which was described in section IV.

A. Assumption and Constraints

We assume that each packet contains several fields such as: the positions of the source node, all the destination (sinks) and the forwarder node. We suppose that each sensor in the network is equipped with several equipments for measuring the distance and the angle of arrival (AOA) of the signal. The security issues are not considered as our challenges in this work.

B. Performance Metrics

We exploit three metrics to evaluate the performance of DS-VBF: packet delivery ratio, the average end-to-end delay, total energy consumption as follow [12]:

1) Packet delivery ratio: is defined as the ratio of the number of packets received successfully at the sink to the number of packets generated by the source node.
2) Average end-to-end delay: is representing the average time for each packet to travel from the source node and receives to any of the sinks.
3) Total energy consumption: defines the total energy consumed in packet delivery, comprising transmitting, receiving energy consumption of total nodes in the network.

C. Simulation Setup

In our simulation setup, sensor nodes are randomly distributed in a 3D field of 500m * 500m * 500m in the X-Y-Z plane (we determine the mobility of all nodes like real environment). The transmission range is set to 100 meters. We employed nodes in random motion while different seeds will generate different results; we choose several numbers of seed and make an average of these results to achieve actual results. Under the condition of random motion, a variety of network configuration is organized; we change the data packet sending rate and also the number of nodes are varied on every experiment. Finally, we analyse the performance based on an average of total achieved results. The data packet size is 76 bytes and control packet is 32 bytes. The total simulation time is 1500, 2500, 3500, 4500, 5500, 6500 seconds and the initial energy is 100j.

D. Results and Analysis

In this study we benefit from both dual-sink architecture methodology and energy efficiency criteria to improve vector based routing protocol concurrently. Based on our simulation results we observe these three significant advantages:

1) Increasing data packet reception ratio
2) Decreasing the average end to end delay in underwater sensor networks
3) Reducing energy consumption

1) Data Packet Delivery Ratio: The data packet delivery ratio of both protocols, VBF and DS-VBF are compared as shown in Figure 2. The delivery ratio is much better in DS-VBF than the VBF. According to this graph in VBF routing protocol, when the simulation time is going up from 1000 to 7000, ratio of packet reception is increasing gradually from 25 to 80, eventually in 7000s, packet delivery stabilized in 70 packets till the rest. In comparison with VBF, in every case, the ratio of packet reception in DS-VBF is considerably higher than VBF. Initially at 1000s, DS-VBF started at 40 which are more than double in comparison with VBF. It can be seen that a sharp increase takes place between 1000s and 3000s.

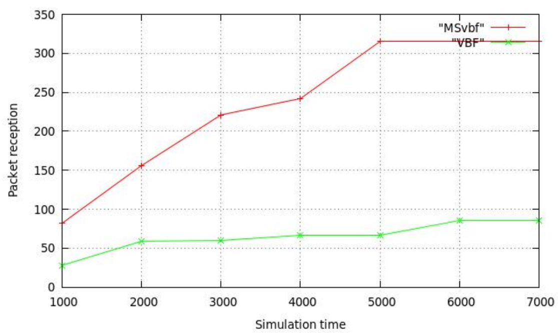

Fig. 2: Ratio of packet reception

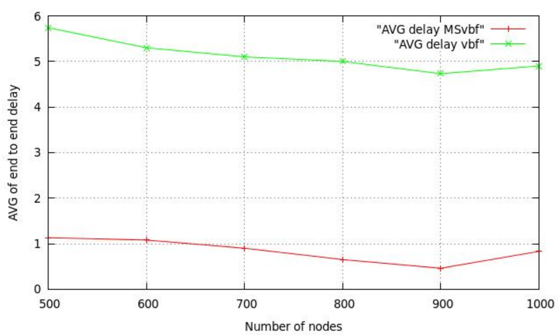

Fig. 3: Average end to end delay

Then there is a mildly growth till 4000s. After that it increased dramatically, followed a period of stability.

However, when the simulation time reaches 5000s, the number of packets reception ratio is stabilized as the number of collisions also go up with the increase in time so forwarding more data packets is not possible. The most striking feature of DS-VBF implementation in comparison with VBF is that, in our implementation the number of packets that are received by target nodes (sinks) stagnated at 320 packets that are more than three times as much as what is experienced in the VBF.

2) End to End Delay: Figure 3 shows the average end to end delay of both the VBF protocol and DS-VBF protocol. Regarding to these considerations, in implementation of DS-VBF the average end to end delay is improved in comparison with the original VBF. In the original VBF this parameter is 5.8 in the 500 nodes and it is decreased gradually with increasing the number of nodes. As it can be followed by Figure 3 the minimum of the average end to end delay in VBF is 4.8 that is obtained by 900 nodes.

As the architecture of VBF is based on single sink deploys on the surface of water, in the transmission of data packet process a bottle neck may occur so it increases end to end delay. In comparison with VBF, DS-VBF improves the average of end to end delay significantly by considering the residual energy of each node and using two sinks at the surface. Initially DS-VBF started with 1.2 second by 500 nodes and plummeting slightly to bottom at 0.4 second. Moreover in the VBF as there is only one unique vector from source node to the destination node (sink) so establishment of one routing pipe affects the routing efficiency and delay significantly. Whereas we observe

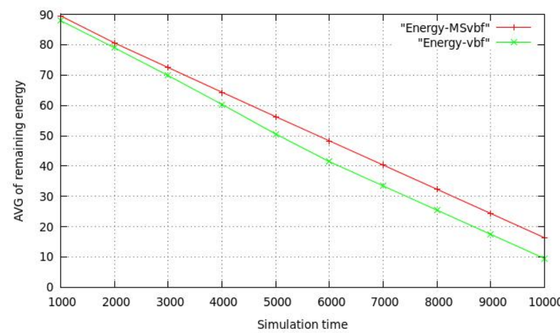

Fig. 4: Average of remaining energy

in DS-VBF there is a substantial end to end delay improvement as in the multiple sink architecture the packet is considered successfully delivered when it reaches to any of the sinks.

3) Energy Consumption: The Average of remaining energy of both VBF and DS-VBF is investigated as shown in Figure 4. This graph shows how residual energy decreases over the time in both VBF and DS-VBF. As shown in the figure 4, the energy consumption of both protocols is increasing with growing in simulation time as more nodes become eligible for forwarding the data packet with increasing in time.

However, VBF limits the number of nodes in accordance with the position information of sensor nodes. In contrast, DS-VBF confines the number of involved nodes, based on two parameters: the position and the residual energy. By looking more closely at the trend for the DS-VBF protocol it can be seen that before 3000s, energy consumption of DS-VBF and VBF are too close for the fact that most of nodes still have more than 70% of initial energy so energy factor has not affected on the routing protocol yet before this time. While after 3000s, there is a decrease which differences energy consumption of the VBF networking system and DS-VBF so DS-VBF saves more energy than VBF. Hence, the reduction in energy consumptions that is achieved after 3000s will prolong the battery life-time of sensors. So DS-VBF, due to the priority assignment techniques becomes more beneficial in long term underwater networks.

VI. Conclusion and Future Works

In this study we investigated routing protocols that were discovered for underwater sensor networking. Nowadays Because of the vital role of the ocean in the humanity's life. Underwater observation coming into a seat of attention. In DS-VBF, dual sinks architecture deployed to increase the number of nodes that are participating in the data forwarding procedure. We deployed two sinks instead of one sink on the surface of water. There is one sink in vector based forwarding protocol (VBF), because of this deployment some specific nodes which are located near the sink are selecting for forwarding data. Thus its energy consumes excessively whereas the other nodes that are far away from sink are not able to participate in routing data packet from source to a node. Therefore by deploying two sinks each node calculates its distance from the sink and will choose the nearest sink and transmit the data to different sinks, because of this, the packet reception ratio will increase significantly, and the average end to end delay decrease to a considerable number. As we show the results by graph in section V-D, packet delivery ratio increased to 70%, also end to end delay reduced more than 80% in comparison with VBF. Limited energy is a challenge in underwater wireless sensor network, to solve the energy problem we introduce node's residual energy into VBF. It means that in contrast with VBF that consider only location information, we consider a new priority, the percentage of remaining energy, in selecting a node as a forwarder. DS-VBF considers both criteria location information and residual energy comprehensively. In DS-VBF, if the remaining energy of a node is less than minimum energy (available in packet), it will drop the packet although it is located close to forwarding vector and a node which is far away but has enough energy will forward data packets to the sinks. Thus we reduce energy consumption 10% versus VBF and balance total energy consumption in the network that causes prolonging network lifetime.

VII. Acknowledgements

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References

[1] Y. Bayrakdar, N. Meratnia, and A. Kantarci, "A comparative view of routing protocols for underwater wireless sensor networks," in *OCEANS, 2011 IEEE-Spain*. IEEE, 2011, pp. 1–5.

[2] I. F. Akyildiz, D. Pompili, and T. Melodia, "State-of-the-art in protocol research for underwater acoustic sensor networks," in *Proceedings of the 1st ACM international workshop on Underwater networks*. ACM, 2006, pp. 7–16.

[3] E. Magistretti, J. Kong, U. Lee, M. Gerla, P. Bellavista, and A. Corradi, "A mobile delay-tolerant approach to long-term energy-efficient underwater sensor networking," in *Wireless Communications and Networking Conference, 2007. WCNC 2007. IEEE*. IEEE, 2007, pp. 2866–2871.

[4] D. Pompili, T. Melodia, and I. F. Akyildiz, "Deployment analysis in underwater acoustic wireless sensor networks," in *Proceedings of the 1st ACM international workshop on Underwater networks*. ACM, 2006, pp. 48–55.

[5] P. Domingues, F. Araujo, and L. Silva, "Evaluating the performance and intrusiveness of virtual machines for desktop grid computing," in *Parallel & Distributed Processing, 2009. IPDPS 2009. IEEE International Symposium on*. IEEE, 2009, pp. 1–8.

[6] P. Xie, J.-H. Cui, and L. Lao, "Vbf: vector-based forwarding protocol for underwater sensor networks," in *NETWORKING 2006. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems*. Springer, 2006, pp. 1216–1221.

[7] N. Nicolaou, A. See, P. Xie, J.-H. Cui, and D. Maggiorini, "Improving the robustness of location-based routing for underwater sensor networks," in *OCEANS 2007-Europe*. IEEE, 2007, pp. 1–6.

[8] P. Xie, Z. Zhou, Z. Peng, J.-H. Cui, and Z. Shi, "Void avoidance in three-dimensional mobile underwater sensor networks," in *Wireless Algorithms, Systems, and Applications*. Springer, 2009, pp. 305–314.

[9] C. Su, X. Liu, and F. Shang, "Vector-based low-delay forwarding protocol for underwater wireless sensor networks," in *Multimedia Information Networking and Security (MINES), 2010 International Conference on*. IEEE, 2010, pp. 178–181.

[10] X. Xiao, X. P. Ji, G. Yang, and Y. P. Cong, "Le-vbf: lifetime-extended vector-based forwarding routing," in *Computer Science & Service System (CSSS), 2012 International Conference on*. IEEE, 2012, pp. 1201–1203.

[11] B. Wei, Y.-m. Luo, Z. Jin, J. Wei, and Y. Su, "Es-vbf: an energy saving routing protocol," in *Proceedings of the 2012 International Conference on Information Technology and Software Engineering*. Springer, 2013, pp. 87–97.

[12] H. Yan, Z. J. Shi, and J.-H. Cui, "Dbr: depth-based routing for underwater sensor networks," in *NETWORKING 2008 Ad Hoc and Sensor Networks, Wireless Networks, Next Generation Internet*. Springer, 2008, pp. 72–86.

[13] W. K. Seah and H. P. Tan, "Multipath virtual sink architecture for wireless sensor networks in harsh environments," in *Proceedings of the first international conference on Integrated internet ad hoc and sensor networks*. ACM, 2006, p. 19.

[14] T. Li, "Multi-sink opportunistic routing protocol for underwater mesh network," in *Communications, Circuits and Systems, 2008. ICCCAS 2008. International Conference on*. IEEE, 2008, pp. 405–409.

[15] D. Pompili and I. F. Akyildiz, "Overview of networking protocols for underwater wireless communications," *Communications Magazine, IEEE*, vol. 47, no. 1, pp. 97–102, 2009.

[16] T. Issariyakul and E. Hossain, *Introduction to network simulator NS2*. Springer, 2011.

[17] P. Xie, *Underwater acoustic sensor networks: medium access control, routing and reliable transfer*. ProQuest, 2008.

[18] P. Xie, Z. Zhou, Z. Peng, H. Yan, T. Hu, J.-H. Cui, Z. Shi, Y. Fei, and S. Zhou, "Aqua-sim: an ns-2 based simulator for underwater sensor networks," in *OCEANS 2009, MTS/IEEE Biloxi-Marine Technology for Our Future: Global and Local Challenges*. IEEE, 2009, pp. 1–7.